MONTHLY NOTICES

OF THE

ROYAL ASTRONOMICAL SOCIETY.

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WILLIAM HUGGINS, ESQ., F.R.S., President, in the Chair.

George Spedding Almond, Esq., Daisy Hill, Dewsbury;
Josiah Owen Corrie, Esq., B.A., Red Cot, Putney Park Lane;
Capt. Joseph Leeman, Aberdeen; and
Herbert Sadler, Esq., Honiton Rectory, Devonshire;

were balloted for and duly elected Fellows of the Society.

Note on a Method of obtaining Equatoreal Motion by means of a simple addition to an Altazimuth Stand. By Lord Lindsay.

If we take a telescope mounted with vertical and horizontal motion, these may be converted into equatoreal motion by the addition of a bar of metal or wood.

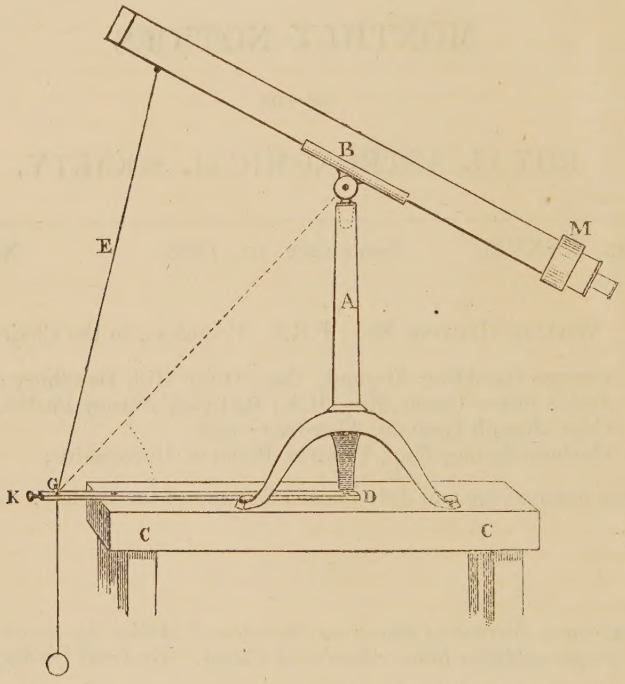
At any convenient distance below the altitude axis of the instrument let a bar be fixed at right angles to the pillar or azimuth axis. In the bar there should be a V-shaped slot, through which a string or wire may slide, and be clamped by a screw pressing it into the angle of the V.

Let the bar project in the plane of the meridian to such a distance that the angle contained between the bar and a line drawn from the V-shaped slot to the centre of motion of the altitude axis is equal to the latitude of the place of observation.

In other words, let the distance of the angle of the V-shaped slot from the central line of the pillar of the instrument be equal to the distance from the upper side of the bar to the centre of motion of the altitude axis multiplied by the cotangent of the latitude of the place of observation.

The object-glass end of the telescope should now be connected with the V-shaped slot by means of a fine wire or string, and a

weight may be attached at the other end of the telescope, in order to keep the wire always stretched. On moving the telescope while the wire remains clamped it will be found, as is



A Stand.
B Centre of Alt. motion.
C Table.
D K Rod.
E Controlling line.
K Pinching screw to clamp-line E.
Angle DGB=Latitude of place.
M Weight to keep E tight.

evident, that the telescope can only move in a parallel of declination. If it is wished to follow another star, the wire must be unclamped and the telescope re-set. The equatoreal motion thus produced will be found to be quite sufficiently accurate for all ordinary purposes.

The method is so simple that I think it must have occurred to other persons; but as I have not seen any account of it in print, I have thought that it might be worth while to mention it to the Society.

Note.—Since writing this paper, my attention has been drawn to the fact that Sir George Airy, in the 15th vol. of the *Monthly Notices*, has described a mounting for a large telescope on this principle; with the difference that he placed the point of attachment of the cord to the north instead of to the south of the telescope.

Description of an Improved Altazimuth Stand for Reflecting Telescopes, with a new Form of Binocular Eyepiece. By W. H. Thornthwaite.

Having been requested by Mr. H. Alers Hankey, of Queen Ann's Mansions, to provide some form of Binocular eyepiece especially applicable to telescopes of large aperture, such as the 12½-inch Equatoreal, with silvered glass mirror, which my firm were constructing for him, several experimental eyepieces of various forms were tried, and also a considerable amount of time and thought devoted to the subject of Binocular vision in connection with the telescope. I hope a short account of these experiments and their ultimate results may prove of interest to the Fellows.

There are two important advantages to be obtained by Binocular vision, the first being, as the name implies, the employment of both eyes, instead of confining observation to either the right or left eye; the second advantage consists in the apparent stereoscopic effect produced when both eyes are employed. In respect to the first-mentioned advantage, it will be admitted that the constant use of one eye must, after a time, be injurious both to that employed and also to its fellow. To take an extreme case, it is found that a single spectacle lens considerably injures the sight; the eye which is *not* assisted by the glass becoming after a time of a different focus to the other. But when both eyes are brought into action no such unpleasant results accrue; and as the observer discontinues his telescopic work, he finds his eyes are not nearly so fatigued by long-continued gazing as they would have been if only one eye had been used.

Secondly, it is impossible that any *real* stereoscopic effect can be noticed in viewing objects so distant, but it may be asserted that a considerable *apparent* effect is produced by Binocular vision. The rotundity of the Sun and Moon, and the mountainous surface of the latter, stand out in bold relief; *Jupiter* and *Saturn* appear *surrounded* by their Satellites, and not, as in an ordinary eyepiece, as a flat picture.

Having made these few general remarks on Binocular vision, I beg to append my own experience, and a short description of the eyepiece now exhibited.

The first eyepiece tried was an ordinary Binocular microscope, with an extra large "Wenham" prism. Except on the Moon, this form was found to be very trying to the eyes, on account of the strain put on them in order to make the two dull fields of the eyepieces coincide: using this form for a few minutes occasioned considerable giddiness. No such visual strain is experienced with a Binocular microscope in its ordinary employment, as the fields are much brighter, and therefore more easily made to coincide. Several other plans of dividing the cone of rays were tried without much success, the great difficulty being that the division must occur so close to the eyepieces, that their

fields, with even moderately low powers, were only partially illuminated.

The Binocular now exhibited has neither of the preceding defects, the fields of low-power eyepieces being entirely illuminated, and it can be used for any length of time without tiring the eyes. Its principal disadvantage is the loss of light occasioned by several reflexions, but as with even moderately large telescopes, the light of the Moon and of some of the planets is excessive, especially to sensitive eyes, this defect must sometimes be an advantage. I may here remark, that I am now constructing a Binocular on a somewhat similar plan, but substituting prisms for silvered flats, and in which therefore the loss of light will be very small.

The principle of this instrument is very simple, and is as follows:—The rays of light from an object-glass or speculum fall on a silvered glass, placed at an angle of 45°, from this they are reflected at an angle of 90° to another silvered glass, parallel to the first, and thence to one eyepiece. But the first reflecting surface is an exceedingly thin coating of silver on a glass with parallel sides; a portion of the light is therefore transmitted through the transparent silver film, and then by two more silvered glasses it is reflected to the other eyepiece. The object of silver film is to avoid the secondary image which would be reflected from the inner side of the glass. The eyepieces are therefore side by side, and have their optical axes parallel; direct vision with each eye is thus obtained. The eyepieces have each an independent focussing slide, and they can be separated to accommodate different observers whose eyes may be various distances apart; this separation is affected by the milled head, the screw on one side of which is right-handed, and on the other left-handed; on revolving the milled head, therefore, the eyepieces are separated or brought nearer together. If solar or first surface prisms were used for the several reflexions, the instrument would form a Binocular for observations of the Sun.

The $8\frac{1}{2}$-inch Altazimuth on which the eyepiece is now shown, in order that the Fellows may roughly test its binocular performance, has been constructed with several important improvements. I will merely call attention to them in order that the Fellows may practically test their utility.

The open tube now adopted is so made that it shows that *any* closed tube may be similarly altered. The altitude clamp is of a novel kind, and is brought for convenience close to the eyepiece. Lastly, the screw motion in azimuth is continuous throughout the entire circle, or may be at pleasure thrown out of gear.

1876, *Nov.* 9.

Measurement of the Direct Effect of Sun-spots on Terrestrial Climates.

By Prof. S. P. Langley.

(*Communicated by E. Dunkin, F.R.S.*)

Since the question of the influence of Solar changes on Terrestrial climates was opened by the elder Herschel, a great number of Meteorological observations have been tabulated and discussed without the apparent attainment of any conclusive result, nor does there seem to be immediate hope of any solution from the study of such Terrestrial effects, while the evidence from these bears so different a meaning according to the interpretation of the compiler.

Though complete knowledge on this point seems still far beyond our reach, yet, if we consent to limit our enquiry to the *direct* effect of Sun-spots on the heat the Earth receives, there is, it seems to me, an untried means, which yields a sufficiently exact solution of the problem. It appears possible at least, to show (within certain definite limits) by how many degrees or parts of a degree Centigrade the Earth's mean annual temperature necessarily varies between a year of maximum and a year of minimum Spot-areas so far as the immediate effect of these on the solar thermal radiation is concerned.

To do this it is necessary,—

(1) To procure from experiment trustworthy measurements of the relative amounts of photospheric, penumbral, and umbral radiation.

(2) To determine the relative photospheric, penumbral, and umbral surfaces, in a maximum and in a minimum year, and (having suitably combined these data) to

(3) Show within what specific limits we can assert that the Terrestrial temperature will be necessarily changed.

The first condition, is so far as I know, heretofore unsupplied, owing to the experimental difficulties which have only lately been overcome. The results of recent measurements at the Allegheny Observatory now published for the first time will furnish these data.

For the second condition, I shall avail myself of the published results of Schwabe, Carrington, De La Rue, and others.

For the third, a method will be employed which, if in some measure novel, is apparently a legitimate deduction from facts in themselves not open to question.

1. *Direct Thermal Measurements of Solar Radiation.*

Since the original observations of Henry, in 1845,* established the important fact that the thermal radiation of a spot is in general

* *London, Edinburgh, and Dublin Philosophical Magazine*, 3rd Series, 1846, p. 230; Poggendorf's *Annalen*, 1846, vol. 68, p. 102.

less than that of the photosphere, nothing appears to have been added to show by how much it differs. If quantitative results have, in spite of their obvious value, never been obtained, it is doubtless owing to the experimental difficulties we meet in passing from the point at which we can say that the spot-radiation is less, to that at which we can say with confidence *how much* it is less. To but partially indicate the nature of these difficulties, we may observe that the umbra of a sun-spot occupies so small an area, that the quivering of the telescopic image, due to atmospheric tremor, commonly causes its libration through a range on either side of its mean position exceeding its own semi-diameter. Whatever the size and stability of the telescope, or whatever the enlargement of the image, or the minuteness of the thermopile we seek to expose only to umbral heat, penumbral radiations will then be registered to some extent, or if it be penumbral radiation we would observe, umbral and photospheric heat will alternately enter with it. This is no serious drawback, if we seek to show only, that the spot as a whole is cooler or hotter without enquiring in what degree; but obviously it is fatal to accuracy, when we would determine by how much the radiation is diminished by each part. We must either take the telescope beyond the limits of our lower atmosphere then, or observe only in those rare and brief periods when the image is still. These periods in our northern climates are always associated during the day with the presence of moisture and haze in the atmosphere. It is almost superfluous to remark that these conditions, which secure a tranquil image, are precisely those most unfavourable to the transmission of radiant heat, and the excessively diffuse and enfeebled rays which form the enlarged image, are, in spite of every precaution, apt to be confused with radiations which reach the pile from extraneous sources.

Trials were made in 1873 and 1874 of a great many plans, for so shielding the pile that it might be absolutely protected against every source of disturbance except the minute pencil of umbral or penumbral rays, with incomplete success, till in the close of the latter year an apparatus was devised by the writer with which, though the time for large spots was passed, satisfactory measures were at last obtained.

The apparatus cannot be fully explained without illustration; the essential conditions of success, however, are that to an eye placed in the position of its working face the part of the spot to be studied and the blackened walls of a chamber surrounded by water at a constant temperature are alone visible, and that provision is yet made for the observer's ability to verify at any moment the position of the image projected on this hidden face, which is maintained at all times in the optical axis. The pile specially constructed by the late Mr. Becker is composed of very minute elements and used in connection with a reflecting galvanometer. The use of a large Equatoreal with accurate clock-work is of course presupposed. That employed was a refractor (and

it will hence be understood that our measurements are confined to luminous heat rays), having an aperture of 13 inches. The projected image was formed on a scale of from four to eight feet to the solar diameter.

The pile was ordinarily first placed in the image of the photosphere, between the spot and the centre of the disk, and the galvanometric deflexion noted; next an exposure of equal length in the umbra was made, and then the observation once more repeated with the pile in the adjacent photosphere between the spot and the limb. The mean of the photospheric readings, after the instrumental reductions are applied, is used as a divisor for the (reduced) umbral reading. The quotient expresses the value of the umbral radiations, in parts of those of the adjacent photosphere. The decrement of heat, as we approach the limb, is, though not exactly, yet so very nearly, in the same ratio for photosphere and spots, that no correction is needed on this account for the present observations. Thirty-six measurements on Umbræ, and thirty-two on Penumbræ, were obtained in the autumn of 1874 and the spring of 1875, as follow:—

Umbral Heat-radiation (Photospheric Radiation = 1·00).	Penumbral Heat-radiation (Photospheric Radiation = 1·00).
0·55	0·86
0·43	0·74
0·49	0·92
0·49	0·98
0·55	0·80
0·61	0·68
0·61	0·82
0·53	0·80
0·55	0·84
0·63	0·73
0·57	
0·50	0·74
0·49	0·83
0·53	0·84
0·54	
0·49	0·75
0·53	0·73
0·57	0·84
0·57	0·79
0·61	0·69
0·52	0·71
0·49	0·81
0·51	0·77

Umbral Heat-radiation (Photospheric Radiation = 1·00).	Penumbral Heat-radiation (Photospheric Radiation = 1·00).
0·54	
0·59	0·89
0·54	0·83
0·52	0·62
0·47	0·82
0·60	0·74
0·53	0·74
0·47	0·82
0·52	0·74
0·52	0·96
0·54	0·89
0·54	0·89
0·58	
Mean 0·54 ± 0·05	Mean 0·80 ± 0·01

The result is, that taking the mean thermal photospheric radiation in the spot's vicinity as unity, the mean Umbral radiation is fifty-four one-hundredths (with a probable error of five one-thousandths), the mean Penumbral radiation eighty one-hundredths (with a probable error of one one-hundredth). These errors include all discrepancies due to the greater or less approach to the limb in the spots measured, or due to absolute differences in their radiation, as well as the errors of observation.

(2.) *Comparison of Umbral and Penumbral Areas in a year of maximum with those in a year of minimum.*

To determine the spotted area of the disk in years of maximum and of minimum, I have taken from a paper by Messrs. De La Rue, Stewart, and Loewy, in the *Philosophical Transactions* ('Researches in Solar Physics,' No. 2, page 115), the following dates:—

Maximum	Dec. 31, 1836	Minimum	Sept. 21, 1843
,,	Nov. 14, 1847	,,	April 21, 1856
,,	Sept. 7, 1859	,,	Feb. 14, 1867

In the same Memoir, under Table 8, is given for every 14th and 28th day of the month from 1832 to 1868, the total spot-area in millionths of the Sun's visible hemisphere, deduced from the observations of Schwabe, Carrington, and the authors; and, by addition of the fortnightly means, we obtain the following annual ones for three years of maximum and three of minimum:—

For 6 months preceding and 6 months following	Dec. 28, 1831	Spot area =		·034670
,, ,,	Sept. 21, 1843	,, ,,	·002555	
,, ,,	Nov. 14, 1847	,, ,,		·031055
,, ,,	April 28, 1856	,, ,,	·000850	
,, ,,	Sept. 14, 1859	,, ,,		·034530
,, ,,	Feb. 14, 1867	,, ,,	·002115	
			·005520	·100255

Whence we find the mean spot-area at any time in a year of maximum = ·001392, in a year of minimum = ·000077; figures which are deduced from a large number of spots distributed with approximate uniformity in longitude, and which hence represent not alone the total spot-area in part of the visible hemisphere, but the total apparent area in parts of the visible disk.

From an enumeration of every Umbral and Penumbral measurement recorded by the authors, from February 7, 1862, to December 31, 1863, we obtain—

$$\frac{\text{Mean Umbral Area}}{\text{Mean Spot Area}} = \frac{21371}{79747} = \cdot 27;$$

$$\frac{\text{Mean Penumbral Area}}{\text{Mean Spot Area}} = \frac{58377}{79747} = \cdot 73.$$

These figures obtained from observations made at a period midway between a maximum and a minimum doubtless represent with approximate truth the relative Umbral and Penumbral areas at other periods. Hence, we conclude that the

Mean Apparent	Umbral	Area in a year of	Maximum	= ·001392 × ·27 = ·000376
,,	Penumbral	,,	,,	= ·001392 × ·73 = ·001016
,,	Umbral	,,	Minimum	= ·000077 × ·27 = ·000021
,,	Penumbral	,,	,,	= ·000077 × ·73 = ·000056

We have now to multiply each area by its measured rate of thermal radiation already found. Thus, we obtain

·000376 × ·54 = ·000203	·000021 × ·54 = ·000011
·001016 × ·80 = ·000813	·000056 × ·80 = ·000044
·001016	·000055

and since it thus appears that the average spot-radiation earthwards in a year of maximum is ·001016, and in a year of minimum ·000055 of that of the apparent disk, it follows that the total effect of the spots in diminishing the solar radiation by the diminished heat from the increased area they periodically occupy, will not exceed the difference of these numbers or

·000961. The figure in the sixth decimal place having no real significance, and that in the fifth being doubtful, we may say that the greatest admissible direct effect of the spots is to diminish the Sun's thermal radiation by a quantity somewhat less than $\frac{1}{10}$ and somewhat greater than $\frac{1}{11}$ of one per cent.

(3) *Limits within which Terrestrial Temperature will be affected by such Changes.*

An exact computation of the effect of the Solar radiations on Terrestrial Temperatures requires a knowledge of the heat the Earth receives from other than solar sources. A number of eminent Physicists have attempted to determine this, but with results which are so discrepant that we can feel, as it seems to me, little confidence in their use. The method here adopted, will not assume any knowledge as to the "temperature of space," or any of the other as yet indeterminate factors, indispensable to a complete solution of the problem: we shall therefore not attain an exact result; but we shall be able to feel confident that we can say with assurance within what limits the truth must lie.

There seems to be no question that a temperature as low as −56°C. has been observed in the open air of the Arctic regions, and it is plain that were the Sun's heat altogether withdrawn, the mean Terrestrial temperature would fall at least as low. Independently of stellar radiation, the Earth receives at the upper limit of its atmosphere a certain amount of heat from non-luminous interplanetary matter, which has absorbed and is radiating obscure heat originally derived from the Sun. Computations of the amount of this obscure radiation indicate that it is more considerable than might be supposed; but as little value attaches (it seems to the writer) to such estimates, they are referred to, only to enforce the statement that were the Sun's heat wholly cut off, whatever the mean temperature the Earth might attain it would certainly be below −56°C., and as its actual mean actual temperature is estimated at from +14° to +16° Centigrade, it is clear that to the entire solar thermal radiations not less than 70° C. of our actual temperature is due.

The least change in solar heat due to the cause we discuss being, as has been shown, $\frac{1}{10}$ of one per cent. of the whole radiation, whose thermometric effect registered here is a change of at least 70°C. we find $\frac{0°\cdot7}{11}$ = 0°·063C. as the *least* change in Terrestrial temperature which we can attribute to the direct effect of the spots.

Again, since the Earth can in no circumstances part with more heat than it possesses, we may, taking the absolute zero as at

$-274°$ C. say that $16°+274°=290°$ C. represents the greatest effect we can assign to the Sun, and that since the greatest change in solar radiation due to the spots is shown to be less than $\frac{1}{10}$ of one per cent. $\frac{2°{\cdot}9}{10} = 0°{\cdot}29$ C., is the *greatest* change in Terrestrial temperature which can be due to this cause.

In all that has preceded it has depended on certain data drawn from observations made by means which exclude the measurement of the thermal effect due to rays in the ultra-red and ultra-violet parts of the spectrum, but were these obtainable, there seems no probability that these conclusions would be materially affected.

To prevent misapprehension, let it be repeated that nothing is here given as being to the writer decisive of the question—whether Terrestrial temperature may not be quite otherwise affected by some varying Solar action of which spots are merely accompaniments—and then, with this understanding, we may reach the following conclusion:—

Sun-spots do exercise a direct and real influence on Terrestrial climates by decreasing the mean temperature of this planet at their maximum. This decrease is, however, so minute, that it is doubtful whether it has been directly observed or discriminated from other charges. Its whole effect is represented by a change in the mean temperature of our globe in eleven years, not exceeding three-tenths, and not less than one-twentieth, of one degree of the Centigrade thermometer.

Allegheny Observatory, Allegheny, Pa.,
1876, *June* 16.

Observations of the Solar Eclipse of 1876, *September* 17.

By John Tebbutt, Esq.

The atmosphere was calm and clear. At the time of first contact the Sun was low, but the undulation along the limb was not so great as I expected; this phase was, therefore, pretty well observed. The observation of the last contact was very satisfactory. The following are the Observatory local mean times of observation:—

	d	h	m	s
First contact	Sept. 17	18	22	2·6
Last ,,	,,	20	1	34·3

The Sun being hidden from the $4\frac{1}{2}$-inch Equatoreal by the house and trees, the eclipse was observed by means of the $3\frac{1}{4}$-inch portable refractor armed with a power of ninety and a green shade. The position of the telescope was about sixty yards east

of the Observatory. Notwithstanding a careful scrutiny, I did not succeed in observing the thorn-like projections of light seen on the solar cusps by Captain Noble and others during the eclipse of September last. The eclipse, which was equal to about one-third of the Sun's diameter, had an interesting effect on a black-bulb thermometer enclosed in an exhausted glass globe.

Windsor, New South Wales,
1876, *Sept.* 21.

Observations of the Lunar Eclipse, 1876, *September* 3, *made at Cadiz.* By Augusto T. Arcimis.

At 7^h I commenced the observations. The state of the atmosphere was magnificent, not a single cloud was visible above the horizon, nor was the slightest breeze perceptible, the sky having an extraordinary and exceptional purity. To the west were visible the last glimmers of the twilight. I made use of a 4-inch refractor (by Secretan of Paris), with an astronomical eyepiece, of the power of 92 diameters. To sketch the projection of the terrestrial shadow I employed a reduced map of the Moon of Beer and Mädler and some photographs of Mr. Warren De La Rue, which I kept constantly before me.

The hours are according to Cadiz mean time; the geographical co-ordinates of my observatory are:

Lat. N. $= 36° \ 31' \ 52''.8$;
Long. W. Greenwich $= 0^h \ 25^m \ 11^s.7$.

At $7^h \ 15^m$ I saw the penumbra which concealed the Oceanus Procellarum, Mare Imbrium, Sinus Æstum, and Mons Carpathus.

At $7^h \ 40^m$ I could see with the naked eye that the light was scarce in the NE. quadrant (invert. vis.) and took a reddish tint.

At $7^h \ 50^m$ (hour of the first contact) the shadow reached the peak Cleostratus (although of the precise moment I am somewhat doubtful), and enlarged itself rapidly to Mons Harpathus and Sinus Proris. Five minutes later I could see with great facility the shadow with the naked eye.

I then applied the spectroscope to the refractor, directing it to the crater Lavoisier; the common solar spectrum appeared as it was expected, but as the shadow advanced and the light became fainter, I detected some of the absorption lines on the red, produced by the Earth's atmosphere.

At $8^h \ 5^m$ the limits of the shadow are, to the east, 38° lat. N., craters Lavoisier, Mairan, Plato, Archytas, Mayer; and ends to the west in 82° lat. N.

I applied again the spectroscope, and in the

darkest part of the lunar disk the spectrum was little visible on account of want of light, but near the limits of the shadow I found the telluric lines on the red, between D and F, and above all between F and C, where they became very numerous.

At $8^h\ 20^m$ the limit of the shadow crossed the 28° lat. N., on the east, craters Briggs, Diophantus, on the middle of Mare Imbrium, crater Autolycus, Palus Nebularum, crater Burg, Lacus Mortis, crater Endymion, and ends to the west in 60° lat. N.

At $8^h\ 32^m$ the shadow reaches the crater Aristarchus ; this was its highest point, on the NE. quadrant.

At $8^h\ 41^m$ the light appeared again upon this crater, and the shadow pursued its descending path.

At $8^h\ 50^m$ the shadow is bounded to the east by 34° lat. N., crater Euler, Mons Apenninus, Hœmus, crater Macrobius, the boreal edge of Mare Crisium, and finished to the west by 30° lat. N.

At $8^h\ 57^m$ time of the middle of the eclipse, according to the Ephemeris, and the shadow begun to the east by 36° lat. N., craters Euler, Manilius, on the middle of Mare Vaporum, crater Vitruvius, and ends to the west by 22° lat. N.

At $9^h\ 6^m$ the limits were, to the east, 40° lat. N., craters Diophantus, Euler, Pytheas, Manilius, Palus Somnii, crater Picard in Mare Crisium, and ended to the west in 18° lat N.

The neighbourhood of the boreal pole which was the darkest, had an orange colour, and the other parts of the shadow were of a livid white, similar to the light of *Saturn.*

I made another analysis with the spectroscope; some of the telluric lines on the violet had disappeared, but those on the red remained very visible.

At $9^h\ 24^m$ the shadow is bounded to the east by 56° lat. N., craters Cleostratus, Sharp, somewhat to the north of Archimedes, Palus Putredinis, craters Menelaus, Jansen, Condorcet, and ends to the west in 12° lat. N.

At $9^h\ 49^m$ the limits are, to the east, 66° lat. N., craters Pythagoras, La Condamine, at half the distance of Harpathus and Senopidus, on the middle of Mare Serenitatis, crater Proclus, Mare Crisium, crater Agarum, and ends to the west by 16° lat. N.

At $10^h\ 4^m$ the last contact took place, with the shadow very near Mare Humboldtianum by 53° lat. N. on the NO. quadrant.

It seems to me that I can point out a small difference in this last contact between the observation and the Ephemeris; those which I have made use of are published here under the title of *Nautical Almanac.*

Observations of Minor Planets with the Transit-Circle at Dublin (Dunsink).

(Communicated by Dr. Robert S. Ball.)

(9) *Metis.*

1875.	Mean Time, Dublin.	α (App.)	δ (App.)	Par.	Obs.—Eph. $\Delta\alpha$	Obs.—Eph. $\Delta\delta$	Mag.	Remarks.
	h m s	h m s	° ′ ″	″	s	″		
Sept. 10	12 54 12	0 12 50·12	− 8 59 44·6	+6·1	−2·46	−14·8	...	
,, 11	12 49 25	0 11 59·61	− 9 5 37·1	+6·1	−2·27	−16·1	9·0	
,, 12	12 44 38	0 11 7·77	− 9 11 28·2	+6·1	−2·49	−18·0	9·0	
,, 13	12 39 50	0 10 15·50	− 9 17 13·1	+6·1	−2·29	−16·3	9·1	
,, 20	12 5 54	0 3 59·72	− 9 55 43·2	+6·2	−2·44	−16·1	8·6	[*Eurydice.* Reddish; certainly far redder than
,, 28	11 26 52	23 56 13·81	−10 32 51·3	+6·3	−2·31	−15·5	9·0	Blue.

(75) *Eurydice.*

Sept. 10	12 41 7	23 59 43·04	− 1 22 57·0	+8·3	+1·06	+ 7·9	9·6	
,, 11	12 36 23	23 58 55·52	− 1 22 57·8	+8·3	+1·10	+ 6·2	10·2	
,, 12	12 31 39	23 58 7·15	− 1 23 0·4	+8·3	+0·98	+ 5·3	9·6	
,, 13	12 26 55	23 57 18·30	− 1 23 2·7	+8·3	+0·99	+ 7·0	9·5	Moon near; very faint.
,, 20	11 53 33	23 51 27·12	− 1 24 12·1	+8·2	+0·87	+ 7·3	8·8	Bluish.

(111) *Ate.*

1875.	Mean Time, Dublin	α (App.)	δ (App.)	Par.	Obs.—Eph. Δα	Obs.—Eph. Δδ	Mag.	Remarks.
	h m s	h m s	° ′ ″	″	s	″		
Nov. 7	11 54 43	3 1 51·85	+25 38 13·5	+2·8	+3·59	− 9·7	...	
„ 11	11 34 59	2 57 51·20	+25 21 5·5	+2·9	+3·59	− 8·4	10·1	

(97) *Clotho.*

Nov. 11	11 59 57	3 22 53·29	− 3 23 59·2	+7·2	+8·03	+26·8	...	
„ 14	11 45 54	3 20 37·71	− 3 41 58·7	+7·2	+8·22	+26·3	9·1	

(13) *Egeria.*

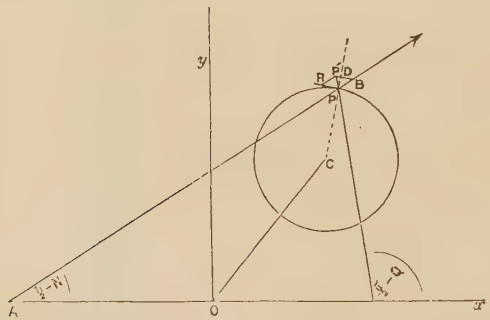
Nov. 7	12 25 1	3 32 14·51	+23 29 37·4	+3·0	+1·17	+ 6 7	...	

The Right Ascensions are based on the *Greenwich Catalogue* for 1864·0, and the Declinations on the Catalogue of the *Vierteljahrschrift* of the "Astronomische Gesellschaft." The comparisons have been made with the Ephemerides of the *Berliner Jahrbuch*. The observations were made by Dr. R. Copeland.

A Method of deducing the Formula for correcting the computed Time of an observed Occultation for Errors in the Elements adopted.

By W. H. Finlay, B.A., First Assistant, Cape Observatory.

In Bessel's method of computing occultations the positions of the Moon and observer are referred to three axes at right angles to one another through the centre of the Earth : of which the axis of z is directed to the star (R.A. $= \alpha'$, Declination $= \delta'$), the axis of x to the point in the equator whose R.A. is $90° + \alpha'$, and the axis of y to the point in the declination-circle through the star whose distance from the equator is $90° + \delta'$. When the occultation takes place the projection of the place of observation on the plane of xy lies on the circumference of the projection of the Moon's disk. Let the figure represent the projection on the



plane xy of the Moon's disk at the time T, and let P be the projection of a place at which the occultation is taking place. Let P′ be an adjacent point in the plane: through P and P′ draw lines parallel to the projected direction of motion of the Moon's centre at the time T, and draw PR touching the circle at P. Then if PP′ be small, P′R is approximately the distance that the Moon's projection must pass through before the point P′ is on the circumference. Draw P′B parallel to the tangent at P, cutting CP produced in D. Let PP′ $= d$, and the angle PP′ makes with the axis of $x = 90° - Q$.

With Chauvenet's notation the angle PA$x = 90° - N$, angle CPB $= \psi$; and the Moon's relative velocity in its projected path is n,—the unit of length being the equatoreal radius of the Earth and of time one mean hour.

Now, from the figure—

$$PP' \cos DPP = PD = BP \cos BPD,$$

that is $PP' \cos (BPP' - BPD) = P'R \cos BPD$;

or $d \cos \{N - Q - (180° - \psi)\} = P'R \cos (180° - \psi)$;

$$\therefore P'R = \frac{d \cos (N - Q + \psi)}{\cos \psi};$$

and the time of Moon's projection describing $P'R = \frac{P'R}{n}$. If P′ be the projection of a point on the Earth's surface not far distant from P, the time at which the occultation takes place at this second station will be approximately $T \pm \frac{P'R}{n}$. A paper on this case by the Rev. T. Chevallier, B.D., will be found in Vol. XIX. of the *Memoirs*. Now consider the case in which the projection of the Moon's centre undergoes slight changes of position owing to slight changes in the elements. These changes may for convenience be attributed to the point P with opposite signs. A slight change common to both Moon and star has scarcely any effect, so we need only consider relative changes.

(i.) If the relative increase of R.A. of the Moon and star be $\Delta (\alpha - \alpha')$, then, π denoting the Moon's parallax, the Moon's centre will be moved through an arc equal to $\frac{\Delta (\alpha - \alpha') \cos \delta}{\sin \pi} \times$ circular measure of 1″, perpendicular to the plane zy; therefore, in this case, PP′ is equal to $\frac{\Delta (\alpha - \alpha') \cos \delta}{\pi}$ and parallel to xO, that is $Q = 90°$.

$$\therefore P'R = -\frac{\Delta (\alpha - \alpha') \cos \delta}{\pi} \cdot \frac{\sin (N + \psi)}{\cos \psi}.$$

(ii.) Let $\Delta (\delta - \delta')$ be the relative increase of declination. Here PP′ is equal to $-\frac{\Delta (\delta - \delta')}{\pi}$ and parallel to yO, that is $Q = 0$.

$$\therefore P'R = -\frac{\Delta (\delta - \delta')}{\pi} \cdot \frac{\cos (N + \psi)}{\cos \psi}.$$

(iii.) Let $\Delta\kappa$ be the increase of the Moon's radius. Then P′ is on the line APB, that is $Q = N$.

$$\therefore P'R = PP' = \frac{-\Delta\kappa}{\cos (180 - \psi)} = \frac{\Delta\kappa}{\cos \psi}.$$

(iv.) Let $\Delta\pi$ be the increase in the Moon's parallax. Put $OC = R$ and angle $COx = 90° - \theta$: then from this change C moves towards O a distance ΔR.

Now $R = \frac{a}{\sin \pi}$ where a is independent of π.

$$\therefore \frac{\Delta R}{R} = -\frac{a\cos\pi}{\sin^2\pi}\cdot\frac{\sin\pi}{a}\Delta\pi \times \text{circ. meas. of } 1'' = -\frac{\cos\pi}{\pi}\cdot\Delta\pi,$$

$$\therefore PP' = -\Delta R = \frac{R\cos\pi}{\pi}\cdot\Delta\pi, \text{ and } Q = \theta,$$

$$\therefore P'R = \frac{R\cos\pi.\Delta\pi}{\pi}\cdot\frac{\cos(N+\psi)\cos\theta+\sin(N+\psi)\sin\theta}{\cos\psi}$$

$$= \frac{\cos\pi.\Delta\pi}{\pi}\cdot\frac{y\cos(N+\psi)+x\sin(N+\psi)}{\cos\psi},$$

where x and y are the co-ordinates of the Moon's centre at the time T.

Since these small changes are independent of one another, their combined effect will be equal to their sum.

$$\therefore \left.\begin{matrix}\text{total correction to the}\\ \text{time T in seconds}\end{matrix}\right\} = \frac{\text{sum of the several values of P'R}}{n}\times h,$$

where h is the number of seconds in the unit of time; that is

$$\text{correction} = -\frac{h}{n\pi\cos\psi}[\sin(N+\psi)\cos\delta.\Delta(\alpha-\alpha')+\cos(N+\psi)\Delta(\delta-\delta')$$
$$+\pi.\Delta\kappa-\{x\sin(N+\psi)+y\cos(N+\psi)\}\cos\pi.\Delta\pi],$$

which is the usual formula, omitting the terms depending on error of eccentricity of the meridian.

1876, *July*.

On the Effect of Wear in the Micrometer-Screws of the Greenwich Transit-Circle. By W. H. M. Christie, Esq.

It has been the practice of observers to examine carefully the accuracy of micrometer-screws on receiving them from the maker's hands; but no one, so far as I am aware, has considered it necessary to make any observation afterwards, though the effect of wear, when observations are made frequently, soon becomes sensible. Under these circumstances, it may be desirable to give an account of a case in which considerable errors have been caused by continued use during a period of more than twenty years.

The wear in the micrometer-screws of the Greenwich Transit-Circle first showed itself by a discordance between the Zenith-points deduced from the Nadir observation and from Stars respectively; though the cause was not suspected till the beginning of 1875, when a change in the position of the division in the field of view of the micrometer-microscopes was found to be accompanied by a change in the discordance from $+0''.7$ to $-0''.6$. This discordance first became sensible in the year 1868; but the error in the

screws, as will be seen presently, existed certainly before that time, though its effect on the Nadir observation was insensible so long as the observations were distributed over the whole range of the screws. This was the case up to 1868, after which the system was altered, the Nadir observation being from that time made with the circle-divisions at 0^r approximately. When the change in the discordance occurred at the beginning of 1875, the values of successive revolutions of the telescope-micrometer, and also of the microscope-micrometer-screws were tested by means of the collimator, and it was found that there was considerable inequality in the latter. To obtain the corrections applicable to the different parts of the screws, four supplementary microscopes (which had only been used occasionally for determining the division-errors of the circle) were mounted and read for comparison with the six ordinary microscopes. These observations are printed in the *Greenwich Observations*, 1875. From 457 comparisons thus made, the continuous curve shown in the diagram has been laid down, the means of the separate apparent corrections tabulated for every tenth of a revolution having been smoothed by taking the means for each adjacent pair, and then the means of these results again in the same way. The ordinates give the corrections to the circle-reading corresponding to the revolutions and tenths of Microscope A, indicated above, which has been taken for convenience of application. Its readings were throughout $0^r{\cdot}13$ less than the mean of the six micrometer-readings.

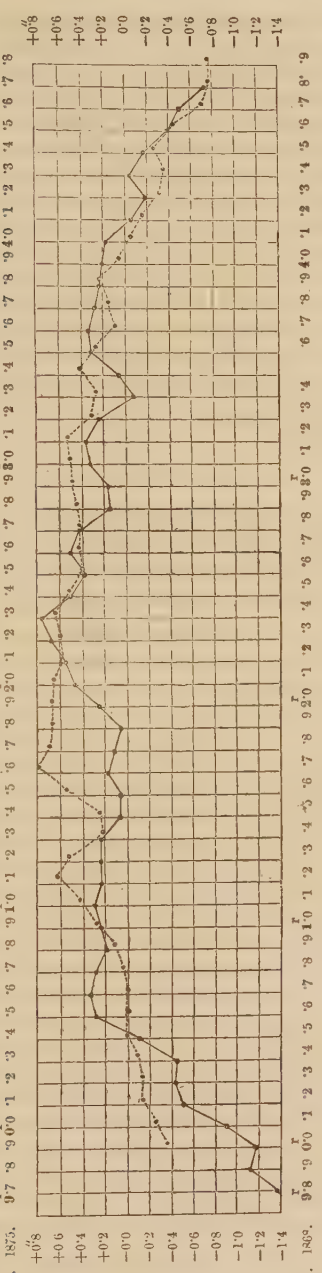
In 1868 similar observations had been made, though with a different object in view, namely, to determine the probable value of the outstanding division-error of the circle. They are, however, equally available for testing the revolutions of the micrometer-screws, and from 289 comparisons thus made, the corrections applicable in 1868 have been found. These are represented by the dotted curve, formed in the same way as that for 1875, but with the origin shifted $0^r{\cdot}08$ to the left, since Microscope A in 1868 read on the average $0^r{\cdot}05$ less than the mean. The revolutions and tenths of Microscope A for the 1868 curve are given below. Both curves are thus virtually referred to the mean of the micrometer-readings. It will be remarked that the two curves are generally similar, giving large positive corrections for the middle of the range; but that the curve for 1868 falls above that for 1875, the corrections being on the whole positive. In fact, the mean of all the individual observations of discordance in 1868 is $+0''{\cdot}20$, whilst in 1875 it is $+0''{\cdot}09$. As these quantities considerably exceed the probable error of the result, which would be about $0''{\cdot}03$, it is possible that some systematic error, such as a difference in the outstanding division-error for the parts of the circle used in finding the Zenith-point with the ordinary and supplementary microscopes respectively, may have affected all the observations. This, however, does not interfere with the comparison of the

two curves, as the ordinates may be supposed reduced throughout by + 0″·20 and + 0″·09 in the two cases respectively. There is another point of difference between the two curves, which depends on the adopted correction for runs, and has the effect of making the axis of symmetry fall somewhat to the left in the dotted curve, which consequently lies above the other at 0ʳ, and falls below it at 5ʳ. Now the wear will take place on the part of the thread against which the spring presses the hollow screw of the micrometer slide, and the cross-wires will consequently be carried further from the head, that is in the direction of increasing readings. Thus, for any given position of the cross-wires, the head will give too small a reading, and a positive correction will therefore be required, this correction being larger for the middle of the range of the screw, which is the part most frequently used. One effect of this will be to increase the run, if the error at the large reading (4ʳ·9 approx.) be greater, algebraically, than that at the small reading (0ʳ approx.), and the same will apply to the correction for runs if corrections be substituted for errors. Now the corrections increase (algebraically) from negative to small positive readings, and decrease from large positive readings onwards, and thus the correction for runs will be greater (algebraically) when the small reading is taken on the negative side of the zero than when it falls on the positive side. In the former case the corrections for error in the screws will be algebraically increased for small readings and decreased for large readings by application of the correction for runs; and this effect is purely arbitrary, since we may choose any part of the screw for zero.

Making due allowance for this, and also for the difference in the sums of all the corrections for the two sets, the dotted curve must be lowered 0″·4 approximately at 0ʳ, and raised 0″·2 at 5ʳ, proportional changes being made for intermediate readings. The agreement between the two curves will then be remarkably close, except for the portion between 0ʳ and 1ʳ, at which point the 1875 curve rises very abruptly, indicating that considerable wear has taken place in that part since 1868. This appears to be fully accounted for by the circumstance that in that year the practice was commenced of taking the Nadir observation with the circle-division at 0ʳ approximately; and, as the observation is regularly made twice a day, there would be a preponderance of some 4,000 observations at this part of the screw in the course of the eight years elapsed since 1868.

It would thus appear that by far the greater portion of the wear in the micrometer-screws has taken place in the seventeen years preceding 1868, and that, except in the part between 0ʳ and 1ʳ, the errors have not sensibly changed since that date. On comparing the several tenths of any one revolution, the corrections for ·7, ·8, and ·9 would appear to be about 0″·2 smaller (algebraically) than the others, but the difficulty of eliminating the effect of the larger corrections is considerable, and the quantities are too small to be determined with certainty.

Corrections to Micrometer-Screws of Greenwich Transit-Circle, 1868 and 1875.



The corrections thus found are considerable; and it is to be remarked that they are of the nature of systematic errors, affecting all the observations of any one star, which would usually be observed in the same part of the field of view of the telescope, and therefore, for several years, with the circle-division about the same part of the range of the micrometer-screw. This points to the necessity for periodic examination of micrometer-screws, though the effect of wear will be sensibly eliminated if the action of the spring be in opposite directions for every pair of micrometers, the readings increasing towards the head for one micrometer, and from the head for the other of each pair.

It may be proper to add, that the accuracy of the screws of the four supplementary microscopes has been tested indirectly by comparison with new screws applied to the six ordinary microscopes, as well as directly by observations on the collimator.

Royal Observatory, Greenwich,
1876, *Nov.* 9.

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*Spectroscopic Results for the Motions of Stars, and of Venus in the Line of Sight, and for the Rotation of the Sun and of Jupiter, made at the Royal Observatory, Greenwich. II.**

(*Communicated by the Astronomer Royal.*)

The recent results for Star-motions have been obtained in the same manner as those given in the *Monthly Notices* for last May, and the general arrangement is unaltered. As, however, it has been suggested by P. Secchi that the results may possibly be dependent on the position of the spectroscope, the reading of the position-circle (or the position-angle of the slit) is here added. The slit lies north and south, and the deviation of the ray is towards the east when the reading is 0°. This is the most convenient position, and is that in which most of the observations have been made. In the earlier measures made in 1874 observations were taken in each of the four quadrants; but, as the position of the spectroscope did not appear to affect the result, the practice was discontinued. All the observations since then are therefore strictly comparable in this respect, and all stars would be equally affected by any error depending on the position of the spectroscope. As a check on the absolute values, however, some measures of the lines in the spectrum of the Moon and of *Venus* have been made in different positions. Special care has been taken to observe the stars in pairs east and west as far as practicable, so that the Earth's motion might affect the several observations with different signs, and also that any error depending on the position of the instrument might be eliminated.

The means have been taken for the whole series of observations of each star, including those given in the *Monthly Notices*

* The Results for the Rotation of the Sun and of *Jupiter* will be given in the *December* number.—[Ed.]

for last May. Where no mean is set down, the result is to be considered as still uncertain. Sufficient observations have now been accumulated to allow of a fair estimate of the probable error in different cases being made. This depends far more on the character of the line observed than on the brightness of the star, being least for those stars which show well-defined lines, such as the *b* group; whilst for stars such as *Altair*, in which the F-line is very broad and nebulous, the uncertainty is so great as to make the spectroscopic method quite inapplicable. It may be remarked, that the range to be expected in a group of observations is five or six times the probable error, so that with a probable error of 10 miles a second the extreme discordance between individual results might be expected to reach 50 or 60 miles a second. P. Secchi would appear to have overlooked this consequence of the theory of errors of observation. The stars have been grouped together, according to the character of their spectra, for the determination of the probable errors in cases where there were less than eight observations. The probable errors of the results are appended with the sign $\pm$.

The measures of the displacement of the lines in the spectrum of the Moon and *Venus* have been made to test both the accuracy of the method of observation and the truth of Döppler's principle. In the case of the Moon, the motion in the line of sight is insensible, and the result of the observations shows a very satisfactory agreement with this. The motion of *Venus* has been observed at both elongations, the comparison being made in some cases with the bright lines of hydrogen or magnesium, in others with the sky spectrum. The observations at the western elongation were made in the forenoon. The calculated motions have been deduced from the daily change of the distance from the Earth, as given in the *Nautical Almanac*. It will be remarked, that the observed motion is rather larger than the calculated, both for the approach and recession; this may be due in part to the disturbing effect of the juxtaposition of two nearly coincident lines. The discordance, however, is small, and may well be a mere chance error in each case; at any rate, as it has the same sign as the motion, it serves to show that there is no systematic error. Generally, the direction of the displacement to be expected was not known to the observer at the time of making the observation.

In measuring the Rotation of the Sun, the great point aimed at was to prevent the Sun's heat from in any way affecting the position of the line observed, by expanding the slit unsymmetrically. Several precautions were adopted to guard against this, and with perfect success, as the measures show. In the first place, a tin screen, perforated with a small hole, 0·2 inch in diameter, was placed three inches in front of the slit, from which it was separated by non-conducting material. When this had been applied, as well as a diaphragm, with a hole of $\frac{1}{50}$ inch close

to the slit, no perceptible rise of temperature in the slit could be detected, a very small portion only being exposed to the Sun's rays. Further, the slit was always placed radially on the Sun's limb, so that the Sun's heat might affect the two sides equally; and, lastly, the slit was placed *alternately* on the east and west limbs, by use of the slow-motion in R.A., and not by allowing the diurnal motion to carry the Sun's image across the slit. By this plan the change from one limb to the other was made so rapidly that no sensible disturbance could take place in the interval; and, further, the observations were made in a continuous series. One set of measures of the east and west limbs, and another of the north and south are given as specimens. The observations were made in the order of numeration. The north and south limbs were compared in exactly the same manner as the east and west limbs, with the slit radial, as a check on the system of observation; but no great care was bestowed on the determination of the position-angle on the Sun's limb, which may be many degrees in error, as it was not easy to verify this point. The observations, however, suffice to show that the precautions adopted have removed the sources of error to which results by former observers appear to have been exposed. Particular care was taken to avoid any bias from previous knowledge of the direction in which a displacement was to be expected, the limb under observation not being determined till after the bisection had been made. In the calculated motion there is some uncertainty, as it is doubtful how far the period of rotation deduced from Sun-spots will apply to the chromosphere, to the rotation of which the observed displacement is due. There would appear to be no reason to suppose that it takes part in the general drift depending on the latitude which has been remarked in Sun-spots.

Many attempts were made to measure the displacement of the F-line due to the rotation of *Jupiter*, but for a long time they were frustrated by the prevalence of haze near the horizon, the planet having large southern declination. On one occasion, however, the spectrum was seen fairly well, and some measures obtained which give a result in remarkable agreement with the calculated value. It is to be remarked, that the method can be applied to *Jupiter* with peculiar advantage, as the equatoreal velocity is very large, and its effect doubled by reflexion. Thus the observed displacement corresponds nearly to four times the equatoreal velocity.

The velocity of light has been taken as 185,000 miles a second, and the distance of the Sun as 91,260,000 miles.

Royal Observatory, Greenwich,
1876, *Nov.* 10.

Motions of Stars in the Line of Sight in Miles per Second. II.

(+ denotes Recession; − Approach.)

1^{div} in the width of the slit corresponds to 0·0013 inch; the weights are on a scale 1–5 for *each* observation; the Means have been taken for the whole series of observations, including former results.

The initials WC and M are those of Mr. Christie and Mr. Maunder respectively.

Date.	Observer.	No. of Measures.	Weight.	No. of Prisms.	Position-Circle.	Width of Slit.	Line compared.	Earth's Motion in Miles per Sec.	Concluded Motion of Star. Measured.	Concluded Motion of Star. Estimated.	Remarks.
					°	d					
							γ Leonis.				
1876 May 15	M	1	2	2	0	2·0	b_4	+17·7	−57·3	−44·3	Indirect comparison; star-lines not very distinctly seen.
15	M	2	6	2	0	2·7 & 1·5	b_1	+17·7	−53·8	−57·2	Indirect comparison; the lines in this spectrum are narrow and sharp.
								Mean	−63·5 ± 7	−60·2 ± 6	
								Probable error of 1 determination	13	10	
							β Ursæ Majoris.				
1876 May 19	WC	1	2	2½	0	3·0	F	+12·3	+52·7	+45·5	Indirect comparison; star-line only seen distinctly for an instant.
								Mean	+23·8 ± 9	+22·1 ± 7	
								Assumed probable error of 1 determination	13	10	

Date.	Observer.	No. of Measures.	Weight.	No. of Prisms.	Position-Circle.	Width of Slit.	Line compared.	Earth's Motion in Miles per Sec.	Concluded Motion of Star. Measured.	Concluded Motion of Star. Estimated.	Remarks.
							Arcturus.				
					°	d					
1876 May 13	M	2	10	2½	0	2·5 & 2·3	b_1	+ 7·9	−33·2	−53·8	Direct comparison; definition very good.
29	WC	2	6	2½	...	1·2	b_1	+11·1	−52·7	−44·6	Direct comparison.
30	M	2	4	2½	0	1·4 & 1·7	b_1	+11·2	−32·7	−25·6	Ind.comp.; image very tremulous; much mist.
July 14	M	3	10	2½	5	3·2 & 2·0	b_1	+15·3	−45·5	−61·7	Indirect comparison; lines not well seen; image tremulous.
17	M	2	4	2½	5	2·1	b_1	+15·3	−38·4	−37·0	Indirect comparison.
24	M	2	8	2½	5	2·6	F	+15·1	−38·2	−52·6	Indirect comparison.
								Mean	−38·3 ± 2·1	−44·5 ± 2·8	
						Probable error of 1 determination			6·7	8·9	
							ϵ^2 Boötis.				
1876 May 13	M	2	10	2½	0	1·6	b_1	+ 6·2	− 6·7	− 9·2	Indirect comp.; star-lines very well defined.
29	WC	3	3	2½	...	1·7 & 2·6	b_1	+ 9·1	+22·0	− 1·7	Indirect comparison; star-line very faint, but sharp and distinct.
July 26	M	2	4	2½	5	1·8	b_1, b_4	+13·4	+26·2	+25·6	Indirect comparison.
								Mean	+ 4·1 ± 6	− 2·3 ± 5	
						Probable error of 1 determination			13	10	

Date.	Observer.	No. of Measures.	Weight.	No. of Prisms.	Position-Circle.	Width of Slit.	Line compared.	Earth's Motion in Miles per Sec.	Concluded Motion of Star. Measured.	Concluded Motion of Star. Estimated.	Remarks.
							α Coronæ.				
					°	d					
1876 July 24	M	2	6	2½	5	3·1	F	+ 12·6	+ 31·7	+ 41·2	Indirect comparison; star-line broad, dark in the centre, but diffused at the edges.
Aug. 16	M	2	6	1½	5	2·2	F	+ 12·4	+ 36·4	+ 37·3	Indirect comparison.
								Mean	+ 36·0 ± 10	+ 39·7 ± 8	
								Probable error of 1 determination	17	14	
							β Herculis.				
1876 July 12	M	2	3	2½	5	2·3	b_1	+ 10·2	− 59·4	− 57·3	Indirect comp.; star-lines very difficult to see.
								Assumed probable error of 1 determination	13	10	
							α Herculis.				
1876 July 12	M	2	2	2½	5	1·5	b_4	+ 8·4	− 15·5	− 14·4	Ind. comp. Star-line well defined towards the blue, but easily confused with others towards the red.
17	M	2	3½	2½	5	3·2 & 2·2	b_4	+ 9·3	− 37·0	− 42·4	Ind. comp.
								Mean	− 29·2 ± 12	− 32·2 ± 10	
								Assumed probable error of 1 determination	17	14	
							β Draconis.				
1876 July 26	M	2	1	2½	5	2·0	b_1, b_4	+ 3·7	+ 12·5	+ 10·9	Indirect comp.; star-lines very indistinct.
Aug. 12	M	1	½	2½	5	2·1	b_1	+ 4·3	− 1·8	− 4·3	Indirect comp.; star-line very difficult to see.
								Mean	+ 7·7 ± 12	+ 5·8 ± 10	
								Assumed probable error of 1 determination	17	14	

Date.	Observer.	No. of Measures.	Weight.	No. of Prisms.	Position-Circle.	Width of Slit.	Line compared.	Earth's Motion in Miles per Sec.	Concluded Motion of Star. Measured.	Concluded Motion of Star. Estimated.	Remarks.
							α Ophiuchi.				
					°	d					
1876 June 26	M	2	3	2½	0	1·1 & 1·7	F	+ 3·7	+ 9·0	+ 9·4	Ind. comp.; image very faint and tremulous.
July 8	M	2	6	2½	4½	2·0 & 3·5	F	+ 6·4	−12·4	−14·8	Indirect comparison; star-line wide and somewhat indistinct.
22	M	2	5	2½	5	2·8	F	+ 9·2	+31·5	+22·5	Indirect comparison; star-line almost as wide and indistinct as that in *Altair*.
							Mean	+ 3·6 ± ·8		+ 0·1 ± ·7	
						Probable error of 1 determination			17	14	
							γ Draconis.				
1876 July 17	M	2	4	2½	5	1·5	b_4	+ 2·3	−21·6	−32·5	Ind. comp.; star-lines (*b*) rather wide & dark.
26	M	3	7	2½	5	2·1	b_4, b_1	+ 2·8	−12·9	−13·2	Indirect comparison.
Aug. 25	M	2	2½	2½	...	1·5 & 1·3	b_1	+ 4·3	−23·2	−19·8	Indirect comparison.
25	WC	1	1	2½	...	2·5	b_1	+ 4·3	−12·5	−16·7	Indirect comparison.
							Mean		−17·1 ± ·6	−19·9 ± ·5	
						Probable error of 1 determination			13	10	
							α Lyræ.				
1876 June 26	M	2	7	2½	0	2·1 & 0·5	F	− 1·2	−33·4	−18·7	Indirect comparison.
							Mean		−38·5 ± 2·7	−34·0 ± 3·2	
						Probable error of 1 determination			9·0	10·6	

Date.	Observer.	No. of Measures.	Weight.	No. of Prisms.	Position-Circle.	Width of Slit.	Line compared.	Earth's Motion in Miles per Sec.	Concluded Motion of Star. Measured.	Concluded Motion of Star. Estimated.	Remarks.
							ζ Aquilæ.				
1876 July 24	M	2	5	$1\frac{1}{2}$	° 5	d 2·0	F	+ 3·5	+41·0	+26·5	Ind. comp. } Star-line broad, dark, but not
Aug. 14	M	2	6	$1\frac{1}{2}$	5	2·0	F	+ 6·4	+42·4	+34·8	Ind. comp. } ill defined.
								Mean	+41·8 ± 9	+31·0 ± 7	
						Assumed probable error of 1 determination			13	10	
							γ Aquilæ.				
1876 July 14	M	2	1	$2\frac{1}{2}$	5	2·0 & 1·9	b_1	− 1·7	−31·0	−30·0	Ind. comp.; almost too faint for observation.
						Assumed probable error of 1 determination			17	14	
							δ Cygni.				
1876 July 24	M	2	7	$1\frac{1}{2}$	5	2·9 & 2·5	F	− 1·6	−29·6	−32.7	Ind. comp. } Star line dark, somewhat broad,
Aug. 14	M	2	5	$1\frac{1}{2}$	5	1·7	F	+ 1·0	− 7·9	−14·1	Ind. comp. } and fairly defined at the edges.
								Mean	−20·6 ± 12	−25·0 ± 10	
						Assumed probable error of 1 determination			17	14	
							Altair.				
1876 June 26	M	2	5	$2\frac{1}{2}$	0	0·7 & 1·2	F	− 6·4	−31·0	− 8·5	Indirect comparison; definition poor.
July 8	M	4	15	$2\frac{1}{2}$	$4\frac{1}{2}$	2·5 & 2·6	F	− 3·5	+35·1	+24·4	Indirect comp.; observations discordant.
						Probable error of 1 determination			46·6	36·3	

Date.	Observer.	No. of Measures.	Weight.	No. of Prisms.	Position-Circle.	Width of Slit.	Line compared.	Earth's Motion in Miles per Sec.	Concluded Motion of Star. Measured.	Concluded Motion of Star. Estimated.	Remarks.
							γ Cygni.				
					°	d					
1876 July 8	M	3	6	2½	4½	1·9	F	− 5·7	− 4·2	− 5·3	Indirect comparison.
12	M	2	6	2½	5	1·8	b_4	− 5·2	−31·4	−28·9	Indirect comparison.
14	M	2	4	2½	5	1·9	b_1, b_4	− 4·9	−32·7	−38·4	Indirect comparison.
17	M	2	4½	2½	5	1·6	b_1, b_4	− 4·5	−18·6	−19·5	Ind. comp.; b_4 seems the easier line to bisect.
26	M	1	2	2½	5	2·6	b_1	− 3·1	−10·2	−14·9	Indirect comparison.
31	M	2	2	2½	5	1·8	b_1	− 2·3	−16·5	−12·3	Indirect comparison; spectrum tremulous, and star-lines confused.
							Mean		−19·7 ± 3	−20·4 ± 4	
							Probable error of 1 determination		8	9	
							α Cygni.				
1876 July 8	M	2	8	2½	4½	1·8 & 2·6	F	− 6·5	−37·7	−35·9	Indirect comparison.
12	M	2	6	2½	5	1·0 & 0·6	b_1	− 6·1	−25·0	−13·2	Indirect comparison.
14	M	2	5	2½	5	2·5	b_1, b_4	− 5·8	−21·7	−43·7	Indirect comparison.
							Mean		−40·2 ± 3	−41·4 ± 3	
							Probable error of 1 determination		8	9	

Date.	Observer.	No. of Measures.	Weight.	No. of Prisms.	Position-Circle.	Width of Slit.	Line compared.	Earth's Motion in Miles per Sec.	Concluded Motion of Star. Measured.	Concluded Motion of Star. Estimated.	Remarks.
							ε Cygni.				
					°	d					
1876 July 17	M	2	2½	2½	5	1·6	b_1, b_4	− 5·9	+ 7·5	+10·5	Indirect comparison; almost too faint a star to observe.
Aug. 12	M	2	1	2½	5	2·1	b_1	− 1·1	+22·4	+25·9	Indirect comparison; star-line very faint and difficult to see.
								Mean	+11·8±9	+14·9±7	
							Assumed probable error of 1 determination		13	10	
							ε Pegasi.				
1876 July 12	M	3	6	2½	5	2·5	b_1, b_2, b_4	−10·4	−27·5	−27·1	Indirect comparison.
31	M	2	2	2½	5	1·3	b_1	− 5·9	−26·8	−14·7	Indirect comparison; spectrum faint, but definition fair.
Aug. 12	M	2	2	2½	5	1·5	b_1	− 2·7	−12·1	−14·0	Indirect comparison; spectrum faint.
23	M	2	1½	1½	5	2·0	b_1	+ 0·3	−28·4	−27·5	Indirect comparison; star-line faint and somewhat indistinct.
								Mean	−24·8±4	−22·7±4	
							Probable error of 1 determination		8	9	
							Fomalhaut.				
1876 July 24	M	3	7	1½	5	3·1	F	− 8·2	+19·2	+23·9	Indirect comparison; star-line dark, somewhat broad, and edges fairly sharp.
Aug. 14	M	2	2	1½	5	2·3	F	− 2·8	−18·1	−19·8	Indirect comp.; star-line not well defined.
							Assumed probable error of 1 determination		13	10	

Date.	Observer.	No. of Measures.	Weight.	No. of Prisms.	Position-Circle.	Width of Slit.	Line compared.	Earth's Motion in Miles per Sec.	Concluded Motion of Star. Measured.	Concluded Motion of Star. Estimated.	Remarks.
							β Pegasi.				
					°	d					
1876 July 31	M	3	6	2½	5	1·8	b_4	−11·4	+16·5	+17·3	Indirect comparison; star-line not easily isolated from others near.
Aug. 12	M	2	4	2½	5	1·6	b_4	− 9·2	+23·7	+26·6	Indirect comp.; light cloud; wind high.
							Mean		+19·4 ± 9	+21·0 ± 7	
							Assumed probable error of 1 determination		13	10	
							α Pegasi.				
1876 Aug. 14	M	2	4	1½	5	2·2	F	− 8·2	− 2·2	− 6·0	Indirect comp.; image rather unsteady.
							Mean		−24·8 ± 8	−18·5 ± 7	
							Probable error of 1 determination		17	14	
							Moon.				
1876 May 29	WC	1	3	2½	...	1·7	b_1	...	− 4·1	...	Moon-line rather faint.
29	WC	1	3	2½	...	2·0	b_1	...	+ 5·1	...	Moon-line rather faint.
30	M	1	1	2½	0	...	b_1	...	−10·8	...	Moon-line hardly visible.
30	M	1	2	2½	0	...	b_1	...	− 5·5	...	Moon-line seen a little better.
30	M	1	2	2½	0	...	b_1	...	− 7·1		
30	M	1	2	2½	0	...	b_1	...	+11·2		

Date.	Observer.	No. of Measures.	Weight.	No. of Prisms.	Position-Circle.	Width of Slit.	Line compared.	Earth's Motion in Miles per Sec.	Concluded Motion of Star. Measured.	Concluded Motion of Star. Estimated.	Remarks.
							Moon—continued.				
Nov. 1	M	1	2	2	62°	d 2·0	F	...	+18·6	...	Definition very variable; Moon-line seen fairly well.
1	M	1	2	2	62	1·8	F	...	+ 8·2	...	Moon-line seen fairly well.
1	M	1	1	2	62	1·8	F	...	−10·4	...	Moon-line not so well seen.
1	M	1	3	2	62	5·0	F	...	−18·6	...	Both the Moon- and comparison-spectrum seen well.
1	M	1	3	2	62	3·2	F	...	− 2·9	...	Both the Moon- and comparison-spectrum seen well.
								Mean	+ 0·6 ± 1·2		
								Probable error of 1 observation	6·0		
							Venus.				
1876 May 16	M	1	2	2	0	6·5	F	...	−14·0	...	Planet's spectrum faint.
16	M	1	2	2	0	1·6	F	...	−11·5	−13·8	Indirect comp.; planet's spectrum faint.
16	M	1	2	2	0	1·6	F	...	−22·1	−13·8	
19	WC	1	1	2½	0	1·9	F	...	−24·2	−12·9	Indirect comparison.
19	WC	1	2	2½	0	1·8	F	...	−14·9	−18·5	
19	WC	1	3	2½	0	2·1	b_1	...	−12·3	−24·8	Direct comp.; planet's lines fairly well seen.
29	WC	1	4	2½	...	1·7	b_1	...	−19·6	−14·7	
29	WC	1	2	2½	...	0·4	b_1	...	−19·2	−14·7	

Date.	Observer.	No. of Measures.	Weight.	No. of Prisms.	Position-Circle.	Width of Slit.	Line compared.	Earth's Motion in Miles per Sec.	Concluded Motion of Star. Measured.	Concluded Motion of Star. Estimated.	Remarks.
							Venus—continued.				
					°	d					
May 30	M	1	3	$2\frac{1}{3}$	0	0·5	b_1	...	− 6·5	− 4·1	Indirect comparison; planet's spectrum faint; wind high.
30	M	1	2	$2\frac{1}{2}$	0	0·5	b_1	...	− 9·0	− 8·2	Indirect comparison; line not so well seen as before.
30	M	1	4	$2\frac{1}{2}$	0	0·5	b_1	...	−10·8	− 8·2	Indirect comparison; line seen much better; wind not so high.
30	M	1	4	$2\frac{1}{2}$	0	1·2	b_1	...	− 7·1	− 5·8	Indirect comp.; lines seen very well.
June 1	M	1	3	$2\frac{1}{2}$	0	0·7	F	...	...	− 7·4	Indirect comparison.
1	M	1	2	$2\frac{1}{2}$	0	0·7	F	...	− 9·6	...	
1	M	1	2	$2\frac{1}{2}$	0	0·7	F	...	− 3·1	− 3·7	Indirect comparison.
1	M	1	1	$2\frac{1}{2}$	0	0·6	b_1	...	−13·7	−14·7	
								Mean	−12·5 ± 1·3	−11·3 ± 1·2	Calculated motion −8·2 miles per second.
							Probable error of 1 observation		5·1	4·5	
1876 Sept. 21	WC	1	...	2	27	5·8	F	...	+41·1	+40·7	Direct comparison with the spectrum of the sky.
21	WC	1	...	2	27	5·8	F	...	+23·1	...	Compared with the spectrum of the sky.
21	WC	1	...	2	27	5·8	F	...	+26·1	...	
21	WC	1	...	2	27	3·3	b_1	...	+34·2	+45·6	Direct comparison with the spectrum of the sky.

Date.	Observer.	No. of Measures.	Weight.	No. of Prisms.	Position-Circle.	Width of Slit.	Line compared.	Earth's Motion in Miles per Sec.	Concluded Motion of Star. Measured.	Concluded Motion of Star. Estimated.	Remarks.
							Venus—continued.				
Sept. 21	WC	1	...	2	27°	3·3 d	b_1	...	+24·3	...	
21	M	1	...	2	27	2·2	b_1	...	+15·1	...	Compared with the spectrum of the sky.
21	M	1	...	2	27	2·2	b_1	...	+15·5	...	
21	M	1	...	2	27	2·2	b_1	...	+18·4	...	
22	M	1	...	2	23	2·4	F	...	+31·3	...	
22	M	1	...	2	23	2·4	F	...	+15·6	...	Compared with the spectrum given by a vacuum tube.
22	M	1	...	2	23	2·4	F	...	+24·1	...	
22	M	1	...	2	23	2·4	F	...	+17·9	...	Compared with the spectrum of the sky.
								Mean	+23·9 ± 3·4	+43·2 ± 11·8	Calculated motion +8·0 miles per second.
						Probable error of 1 observation			11·9	16·6	
1876 Oct. 12	WC	1	4	2	26	3·0	b_1	...	+31·3	+28·7	Direct comparison with the spectrum of the sky.
12	WC	1	4	2	26	3·0	b_1	...	+35·3	+28·7	
12	WC	1	2	2	26	3·0	b_1	...	+10·7	...	Compared with the spectrum of the sky.
12	M	1	4	2	26	2·8	b_1	...	+9·6	+16·6	
12	M	1	4	2	26	2·8	b_1	...	+8·1	+16·6	Direct comparison with the spectrum of the sky.
12	M	1	4	2	26	2·8	b_1	...	+15·5	+16·6	
								Mean	+19·1 ± 4·9	+21·4 ± 7·4	Calculated motion +7·9 miles per second.
						Probable error of 1 observation			11·9	16·6	

Date.	Observer.	No. of Measures.	Weight.	No. of Prisms.	Position-Circle.	Width of Slit.	Line compared.	Earth's Motion in Miles per Sec.	Concluded Motion of Star. Measured.	Concluded Motion of Star. Estimated.	Remarks.
							Venus—continued.				
					°	d					
Nov. 7	WC	1	3	4	30	3·3	b_1	...	+ 15·0	+ 7·6	Direct comparison with the spectrum of the sky.
7	WC	1	3	4	30	3·3	b_1	...	+ 13·5	+ 7·6	
7	WC	1	3	4	30	3·4	b_2	...	+ 11·8	+ 6·5	
7	WC	1	3	4	30	3·4	b_2	...	+ 11·2	+ 6·5	
7	M	1	4	4	30	3·8	b_1	...	+ 9·4	+ 8·4	
7	M	1	4	4	30	3·3	b_1	...	+ 12·9	+ 11·2	
7	M	1	2	4	30	3·7	F	...	+ 7·7	+ 6·5	
7	M	1	3	4	210	3·8	b_1	...	+ 4·4	+ 7·2	
7	M	1	3	4	210	3·8	b_1	...	+ 14·9	+ 16·8	
7	WC	1	2	4	210	7·0	b_1	...	+ 21·2	+ 10·4	
8	M	1	2	4	120	3·3	b_1	...	+ 17·7	+ 9·0	
8	M	1	1	4	120	2·2	b_1	...	+ 7·9	+ 4·8	
8	M	1	3	4	120	4·7	b_1	...	+ 11·8	+ 10·0	
8	M	1	1	4	300	3·6	b_1	...	− 0·7	+ 0·0	Indirect comparison.
8	M	1	2	4	300	3·7	b_1	...	+ 10·0	+ 12·4	Direct comparison with the spectrum of the sky.
8	M	1	3	4	300	3·7	b_1	...	+ 11·7	+ 12·4	
							Mean		+ 11·7 ± 1·1	+ 9·1 ± 0·6	Calculated Motion + 7·3 miles per second.
							Probable error of 1 observation		4·5	2·4	

An Endeavour to simplify the Method of making the Correction for the Spheroidal Figure of the Earth in Lunar Observations, and particularly with reference to its effect upon the "Lunar Distance." By F. C. Penrose, Esq.

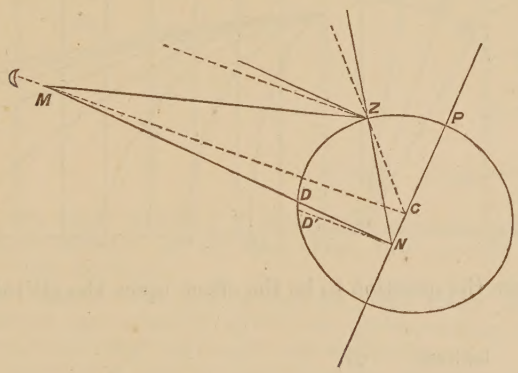
The correction for the Spheroidal Figure of the Earth is generally neglected in ordinary Lunar Observations. Nor is this to be wondered at, if the navigator is expected to follow the rules generally laid down for the purpose.

In endeavouring to simplify these rules, I lighted upon a plan which cleared up these difficulties to a very great degree; but, as it has been since pointed out to me, the discovery has been anticipated and its value already recognized.

This, however, does not, I think, preclude my bringing it before such members of the Society as are unaware of it, especially as it does not appear in the works mostly in use; and I indulge in the hope, with the help of a graphic process, to render the management of this correction so easy, that there can be no reason for its being any longer neglected.

The quantity involved is sometimes so large as to be out of all proportion greater than the smaller corrections which are often scrupulously attended to: such as great accuracy in interpolating between the arguments of parallax, or in allowance for barometer and thermometer under ordinary conditions.

[I am not advising the neglect of these corrections; but only that when time is an object, they may be followed up somewhat more roughly; so that the time saved in them may be used for the correction for the Spheroid.]



When the Moon is referred to the Earth's centre C by the polar distance (viz.: through PCM and the radius vector CM), for any point Z at any latitude, its parallax must be reckoned from the line ZC, which does not agree with the plumb-line—

the standard of our measuring instruments—which intersects with the polar axis at some point N beyond the centre.

By referring the observation to the point N, the complication of having the astronomical zenith and the geocentric zenith to deal with, which troubles all azimuths except the meridian, is avoided.

This only requires that the value of C N for any latitude should be tabulated (call this value n), and that an allowance should be made to the declination given in the *Nautical Almanac*, $= n \cos D$; if D be Moon's declination (geocentric).

This correction is always to be subtracted from the polar distance. But inasmuch as in this reckoning, the radius measuring the Moon's horizontal parallax for the latitude in question is N Z, instead of C Z, the tabular H P will have to be varied accordingly.

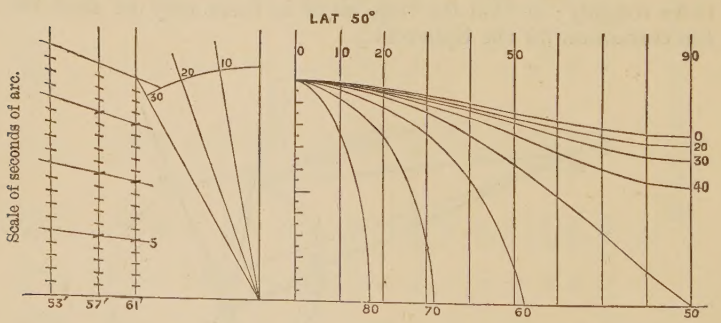
If, therefore, to the table above referred to are added the values of N Z, as well as those of n, the correction can be made by inspection.

These tables are given below.

If these corrections are first made in the original elements of computation of any lunar observation, the purpose is answered.

If, for instance, an altazimuth of ☽ has been observed, and these corrections be given to the elements of declination and parallax (there is no trouble with the azimuths), the Moon's hour-angle will at once be obtained.

But in many cases it may answer better to add this spheroidal effect as a correction afterwards, and for that purpose I have prepared a specimen-diagram adapted to latitude 50° (of course, North or South as the case may be).



Suppose the question to be the effect upon the altitude when in—

Latitude	50°
Declination	20
Altitude	40°

Parallax 57′

These give an hour-angle of about 51°.

The ordinate in the diagram corresponding to these places shows 13″·4, but when reduced for declination by applying it to the slant line, it gives 12″·4, the answer required.

The hour-angles figured 0, 10, 20, 50, 90 repeat after 90° ; for instance, the value corresponding to 130° is the same as that of 50°, etc.

Generally, the correction must be added to the altitude ; but, if Moon's declination is greater than the latitude, the sign must be reversed, and it must be subtracted.

Probably the most important view of this correction is its bearing on the Lunar Distance.

This can be readily measured upon similar diagrams, if what has been called Latitude be taken for the star's altitude.

I have put together a case, which can be worked upon the diagram given :—

	°
Let the Latitude be	50
Moon's Declination	20
Apparent Altitude	30
Distance	30

These values require Moon's hour-angle about 66° 30′, and the azimuth-angle with respect to the star, 30°.

Treat the first on the diagram with hour-angle 66° 30′, altitude 30°. The ordinate on the chart gives 13″, but applied to the declination line, 12″·4.

Now consider the star's altitude as 50°, and the combined azimuth 30°.

The ordinate reads ·76 on the division under hour-line 0.

Then	12·4	
	·76	
	7··	
	87·	
	94	*Answer.* 9″·4.

There are cases where 9″·4 in a lunar distance would influence the longitude by 45ˢ, and often this amount of 9″·4 would be much exceeded.

Similar diagrams can also be used for many other purposes : as for instance, approximately giving the corresponding azimuth to a given altitude and hour-angle and declination.

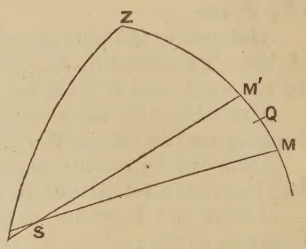
They may also be used to form the entire operation of clearing the distance, instead of the small correction only above given, with a fair amount of accuracy.

Clearing the distance by means of the diagram in the example above given, HP being 57′, parallax in altitude affected by refraction = 50′ 56″. This worked out fully gives 49′ 38″ for

its effect upon the distance. Using the decimal fraction previously found upon 50′ 56″, we obtain 49′ 28″.

And even where exactness is required, an approximation easily obtained will enable the work to be shortened, in this manner, viz. :

Let Z be the Zenith; M the Moon's apparent altitude; MM′ the Parallax in altitude $= p$.



If MM′ were very small, the effect would be simply$=p$ cos M $= \frac{dz}{ds}$.

This will not, in ordinary cases, be sensibly incorrect if the point Q half-way between M and M′ be taken, and a proper allowance be made for the alteration of SM. The altitude of Q comes at once by applying $\frac{p}{2}$; and the corresponding value of SQ results from the approximation referred to derived from the diagram.

In estimating these corrections, whether of the whole effect known as clearing the distance, or only the part resulting from the spheroidal figure, which is the particular object of this discussion, it is of course of primary importance to know whether it should be estimated + or −.

This will always depend upon the angle at the Moon; calling this M, when M is greater than 90°, the distance will be increased, when less, diminished. When the star's altitude is greater than that of the Moon, the angle at M is always acute. Also, when the distance SM is greater than the star's co-altitude, M is always acute.

Rule for doubtful cases :—M will be acute or obtuse, according as cos b is greater or less than cos z cos s.

1876, *Nov.* 10.